TIROS I PHOTOGRAPHS OF THE MIDWEST STORM OF APRIL 1, 1960*

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[Manuscript received October 10, 1960; revised October 26, 1960]

ABSTRACT

The midwest cyclone of April 1, 1960 is described from the standpoint of a series of TIROS cloud photographs. Cloud features having different appearances are related to the air masses and mechanisms involved. The cloud pictures are also used in outlining a possible application for objective weather map analysis in sparse data regions.

1. INTRODUCTION

TIROS I, the first photographic meteorological satellite, was launched on April 1, 1960. More than 20,000 photographs of the earth's cloud cover were received during its useful life span of 76 days. The satellite was equipped with both wide- and narrow-angle television cameras. A more detailed description of the engineering aspects of TIROS I may be found elsewhere [1].

One of the first storms photographed by TIROS I as it circled the earth was the Midwest storm of April 1, 1960 (fig. 1). Among the most striking cloud patterns photographed by TIROS I are large-scale vorticies, such as can be seen in frames B and C of figure 2. Frame B has been used as an example previously [2] owing to its classical structure of cyclonic center and frontal position. In this report it will be studied in greater detail as an integral part of the storm situation.

The Midwest storm developed as a lee disturbance to the east of the Rockies in conjunction with an intrusion of polar maritime air from the west. Individual TIROS cloud photographs presented in figures 2, 3, and 4 indicate the details of the cloud structure in various portions of the storm. The letter label attached to each photo appears on the map in figure 1—capitalized to indicate the satellite's position and in small type to locate the optical center of the picture. Photos A, B, and C in figure 2 were taken near 2028 GMT, April 1 looking back along the orbit as the satellite moved southeastward off the Louisiana coast. The remaining photos, D, E, F, G, and H in figures 3 and 4 were taken near 1843 GMT on the preceding orbital pass looking northwestward over the upper Plains and Great Lakes region. The areas viewed in narrow-angle photos G and H are indicated on the wide-angle photos D and F. The wide-angle photos were fitted with computer-produced perspective geographic grids. Sample grids are presented for frames B (fig. 2) and E (fig. 3). Precision of the gridding procedure requires knowledge of the satellite spin axis with respect to some frame of reference when the picture was taken. This involves knowing the spatial location of the optical axis of the camera systems and an accurate estimate of the time when the picture was taken. A more complete discussion of the gridding process may be found elsewhere [3].

One hundred photographs were taken by the TIROS wide- and narrow-angle cameras during the two passes of interest here. Fortunately, some of these pictures provide an excellent view of the entire storm area. After careful examination of the photographs, two composite sketches were created from eight gridded photos to provide a schematic representation of cloud brightness and coverage. Although individual cellular patterns and filament structures are indicated, there has been no attempt to obtain cell-for-cell accuracy. The mosaic sketch on a standard map base is broken into two segments because of the mis-match arising from movement of cloud features during the 100 minutes between pictures which overlap geographically from one pass to the next. Figure 5 presents the mosaic of the southern portion of the storm and figure 6 indicates the northern portion. The entire cloud pattern in outline form is also indicated with light stippling in figure 1. The mosaic sketches of figures 5 and 6 have been divided into Roman-numbered regions to facilitate the discussion. It will be convenient to indicate the sub-regions of the sketches by number and also refer to the individual photos by letter without regard to figure number in order to reduce wordage. Since the paper largely involves the description of pictorial details, the reader is cautioned to relate the discussion continuously to the corresponding pictures in order to maintain meaningful continuity.

The discussion in this paper represents an attempt to relate some of the outstanding features of the cloud

*This research has been supported by the National Aeronautics and Space Administration.

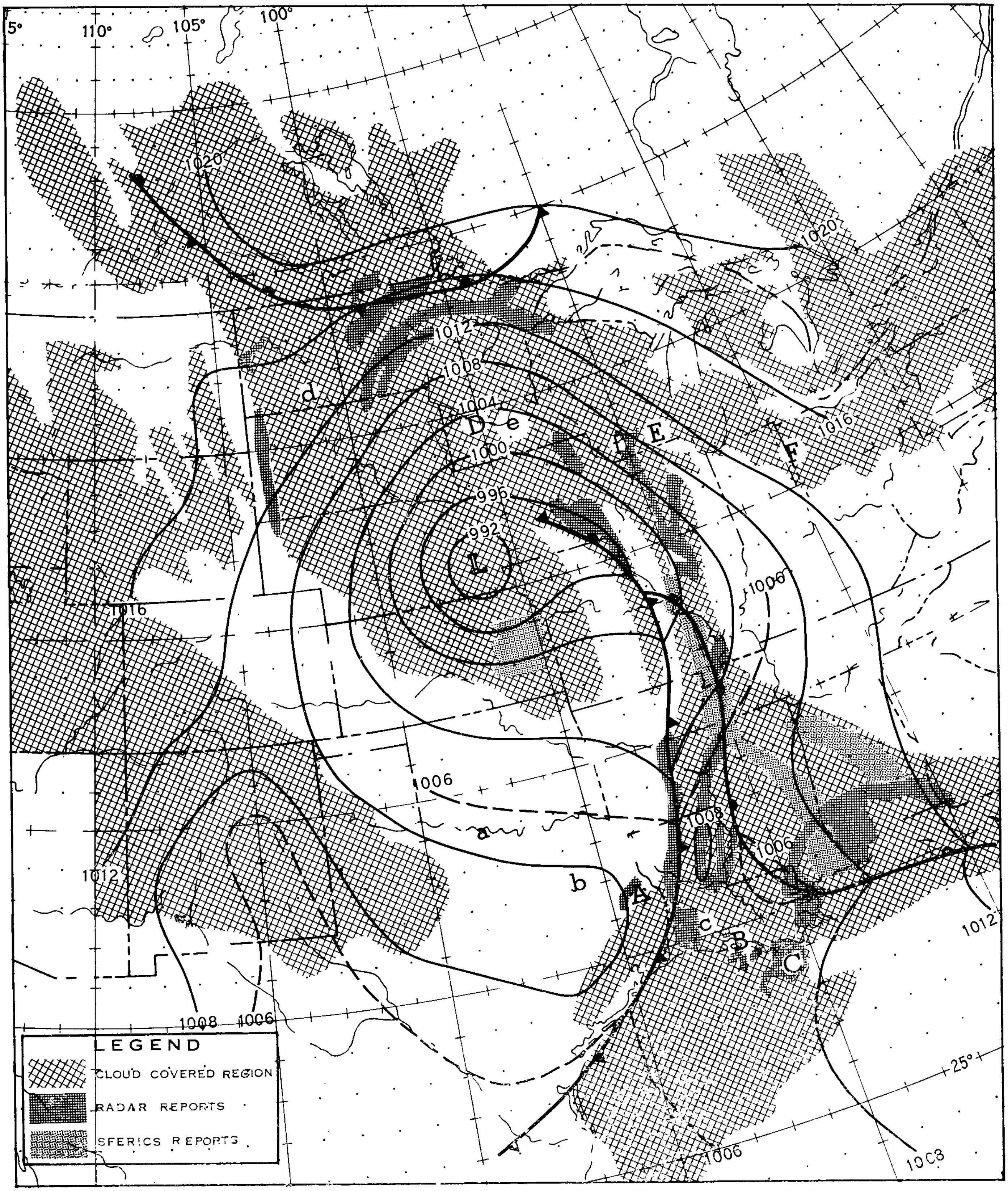

FIGURE 1.—Sea level chart, 2100 GMT, April 1, 1960, with cloud cover area and radar and sferics reports. Letters refer to satellite photographs.

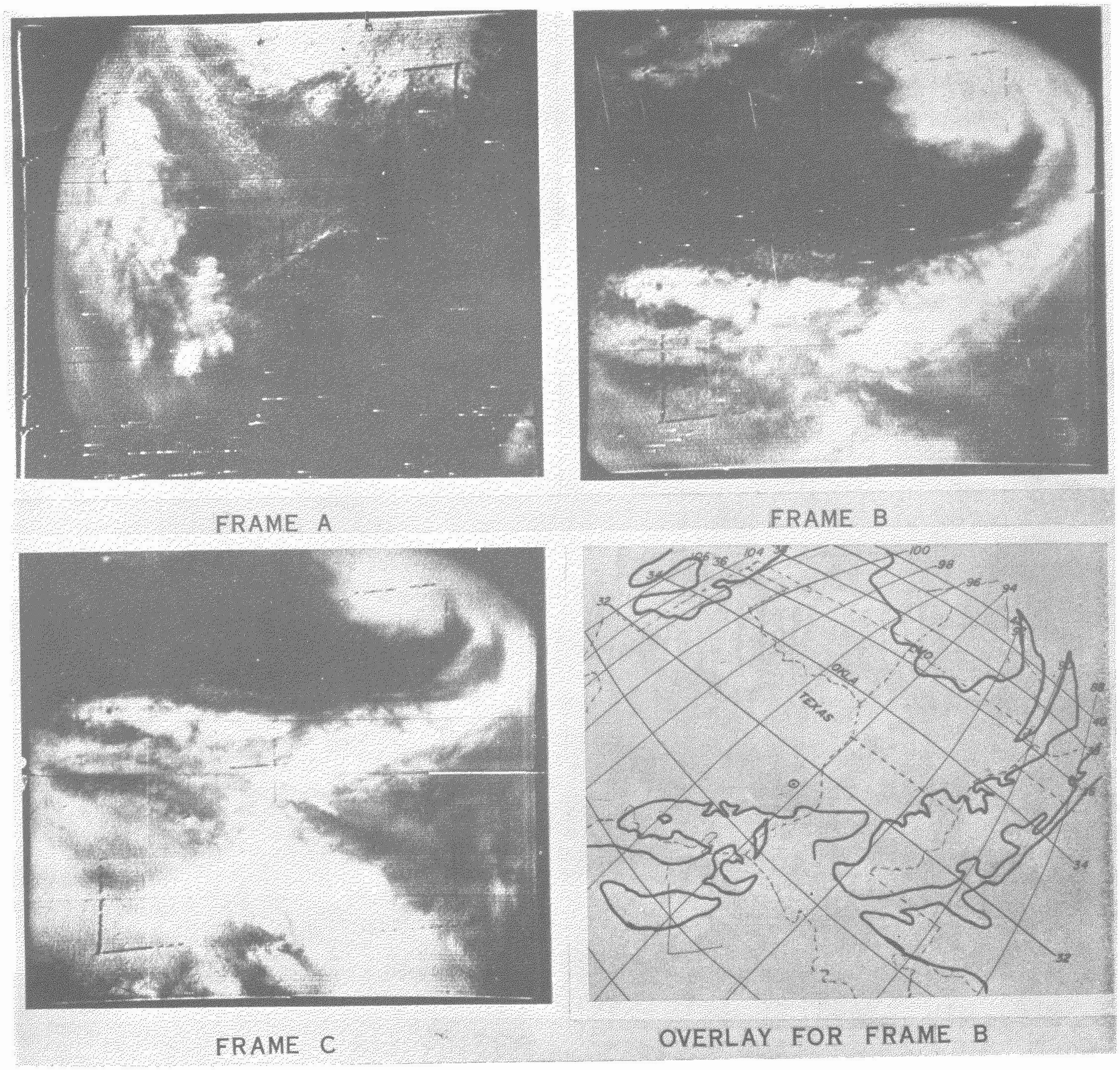

FIGURE 2.—TIROS wide-angle cloud photographs taken over points A, B, and C of figure 1, and a grid overlay for frame B. (The dotted circle gives the optical center of the picture.)

photos to other meteorological observations and analyses. In particular, comparisons are made between the cloud cover pattern and objective weather analyses pointing up the potential usefulness of the cloud information for improvement of such analyses in sparse data regions.

2. CLOUD PHOTOS

The following comments concerning the individual photos are designed to point out the main features in each picture and to relate them to the composites in figures 5 and 6. Also, somewhat in the manner of a cloud atlas, an effort is made to identify the types of clouds being viewed, but without discussing the weather situation in its entirety. This identification is however dependent upon corroborating evidence obtained from the standard meteorological observations of clouds and weather, both from the ground and from airplane reports. Relationships of the cloud pictures to circulation patterns and other

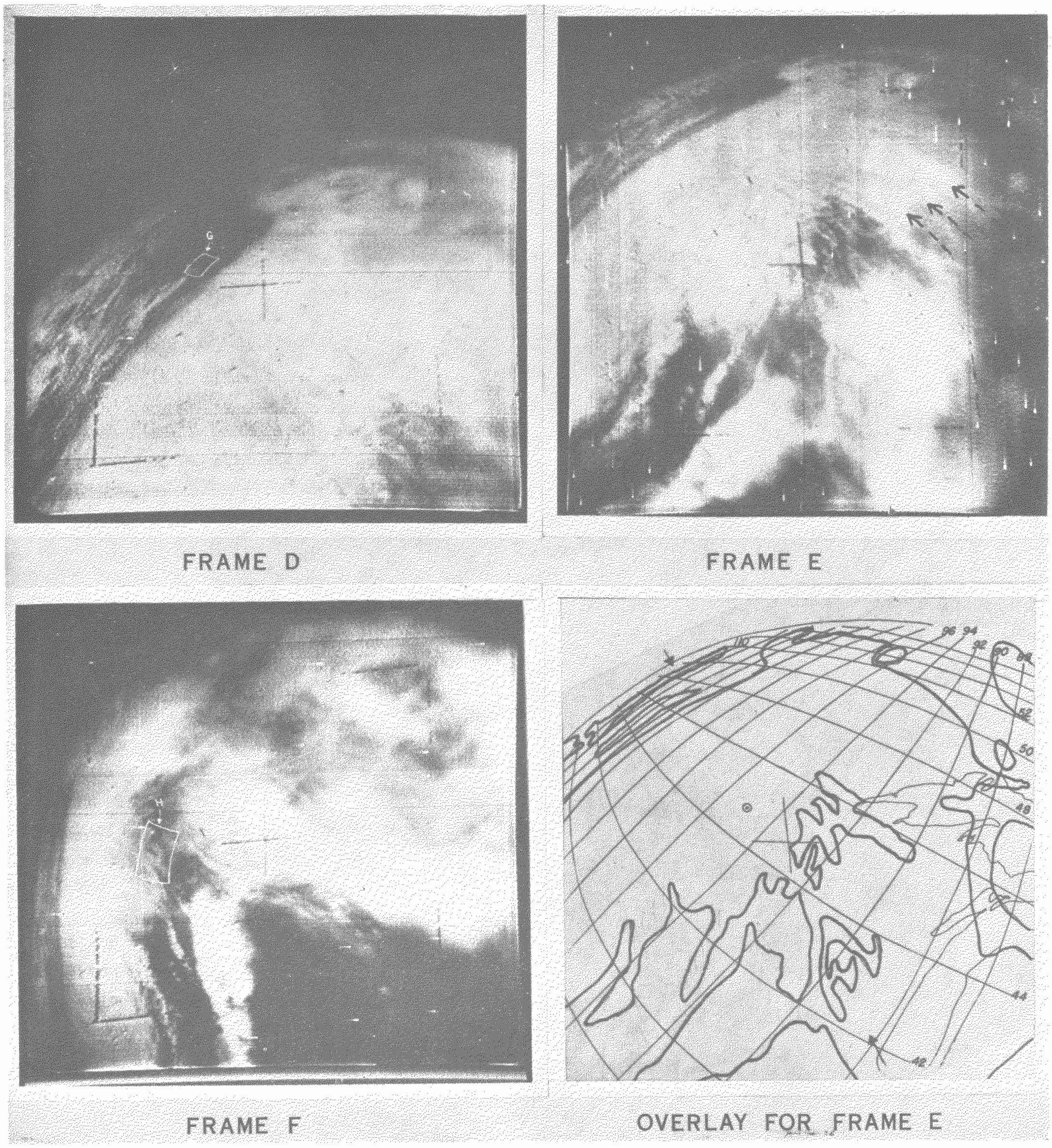

FIGURE 3.—TIROS wide-angle cloud photographs taken over points D, E, and F of figure 1, and a grid overlay for frame E. (The dotted circle gives the optical center of the picture.)

meteorological mechanisms will be treated in the ensuing section of the paper.

In the right foreground of frame A (See also fig. 5) is a predominantly clear region extending from eastern Texas into Missouri. The textured edge of a dense overcast region is visible at the top of the frame over Kansas. The cloud mass to the left has a marked cellular structure throughout, with a suggestion of thin upper clouds. The leading clump of cells is near Lubbock, Tex. The main portion of this cloud mass extends over most of New

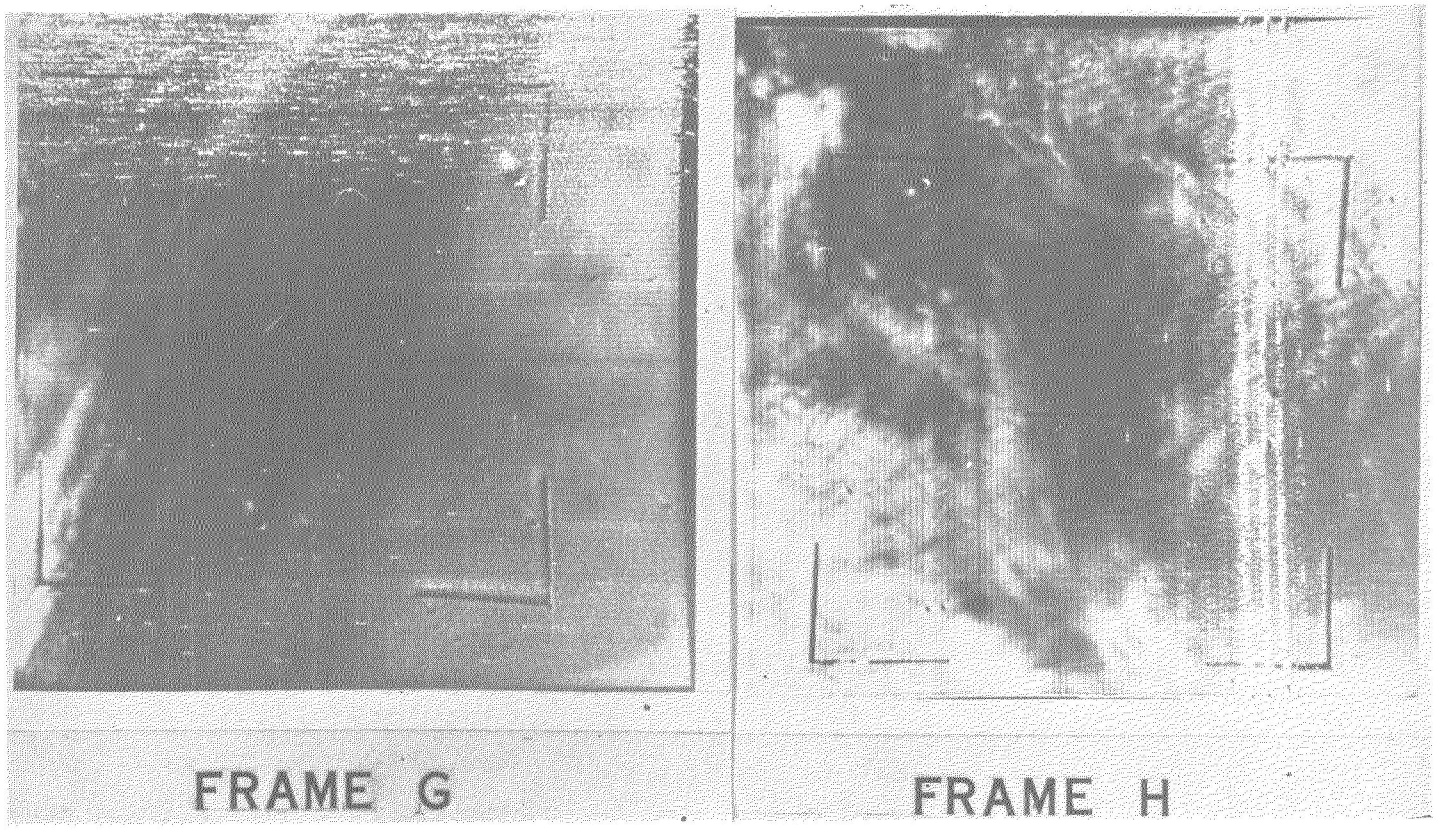

FIGURE 4.—TIROS narrow-angle cloud photographs taken over areas G and H shown in frames D and F of figure 3.

Mexico and northwestward. A filmy veil of clouds appears to emanate from the upper left of the photo (near Denver) and terminates in a brighter streak near the center (intersecting the southern Oklahoma border).

Frame B was taken one minute after frame A. The Texas-New Mexico cloud now appears much foreshortened near the top of the picture. More of the solid overcast region is now visible in the upper right. The overcast extends over much of Nebraska as indicated by the accompanying geographic overlay.

A wealth of new detail appears in the foreground. Faint patches of stratocumulus are lined up horizontally across the photograph along the lower boundary of the clear area. These wisps continue to the right into a brighter wedge of cloud containing cumulonimbus and upper cloud at its junction with the overcast region in the upper right portion of the photo. The features described above are located in the mosaics of figure 5 along a line through central Arkansas and northward into Iowa. Much brighter clouds of great variety extend across the photo in a broad belt immediately below and paralleling the features just described. Widespread shower activity with cumulus and cumulonimbus clusters, together with middle and high clouds, occupies the band from the upper right down to the bright "finger" in the lower central foreground of the picture. A cloud system, with parts almost as bright, extends on to the left. The brighter portion of this left branch near the center of the photo, is a region of cold frontal shower activity. Two sizable clear patches appear as black spots farther to the left in a post-cold-frontal region of waning shower activity. The larger, relatively clear, horizontal areas below this cloud region are located over the Gulf of Mexico near the northern portion of the Texas coast.

Frame C was taken 30 seconds later and largely overlaps frame B. The important extension of the viewed area is in the foreground. The bright region at the lower edge of frame B is now located near the center of the picture with a broad, very bright band extending to the lower right. This band, extending from New Orleans eastward along the Gulf coast consists of an almost solid mass of cumulonimbus activity with extensive middle and upper cirriform overcast. The gray area to the lower left extending off the Louisiana coast contains patchy lower clouds with little or no upper cloud cover. The darker region in the lower right, covering parts of central and northern Mississippi and Alabama represents mostly high, broken cloudiness with a few patches of lower, cumulus shower activity.

Frame D of figure 3 is predominantly a view of the extension of the dense overcast area over Kansas and Nebraska as seen in frames A, B, and C. Most of the part shown here, covering the Dakotas, appears equally dens e and uniform. These are multi-layered, precpita-

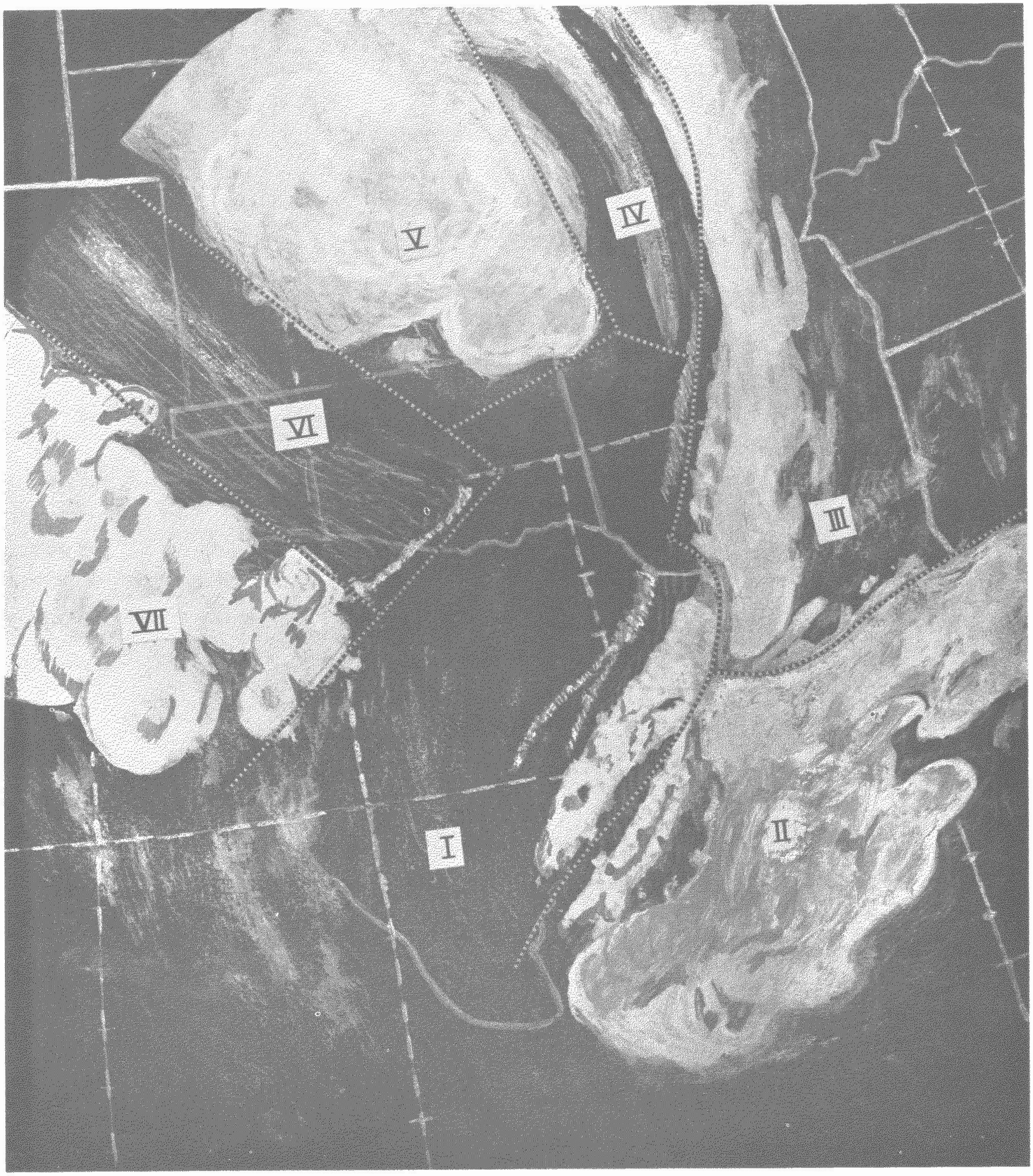

FIGURE 5.—Mosaic representation of TIROS wide-angle cloud photographs taken near 2028 GMT, April 1, 1960.

tion-bearing clouds. The possibility of an effect of snow cover is discussed later. A narrow-angle picture,* viewing the center of the lower half of this frame gives only a faint suggestion of a cellular pattern. Frame G of figure 4 presents a detailed narrow-angle camera view of the west flank of this large overcast in the area marked on frame D. The bright cloud in the lower left evidently contains rows of cumuliform clouds. There also appear to be streaks of thin clouds parallel to the edge of the large overcast. The cloud pattern to the left in frame D is located over Wyo-

*Unfortunately, strong electronic interference contaminated this photo making the printing reproduction marginal in quality.

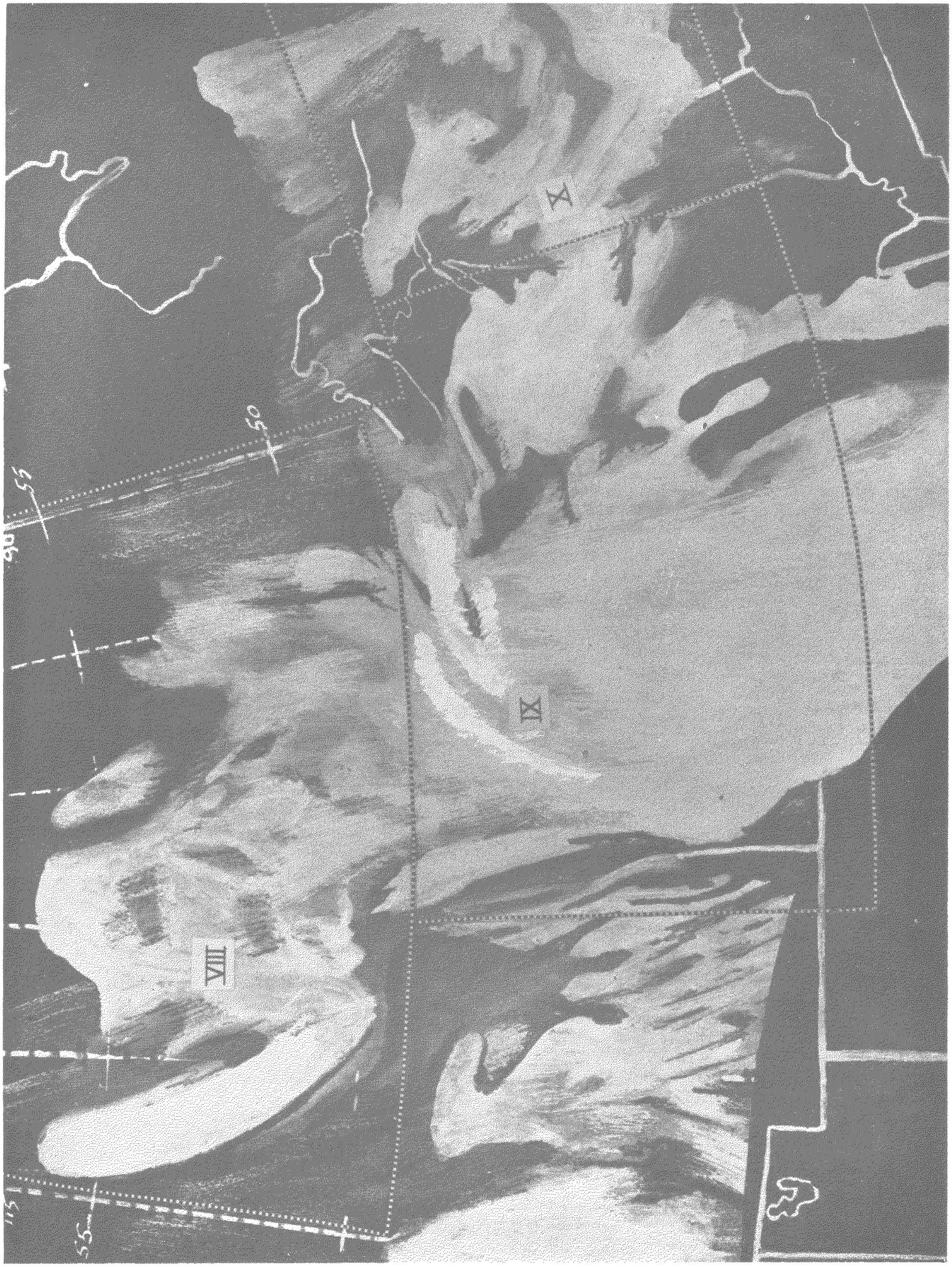

FIGURE 6.—Mosaic representation of TIROS wide-angle cloud photographs taken near 1843 GMT, April 1, 1960.

ming with the streaks oriented roughly north-south. Some thin cirrus clouds exist here but the brighter portions are rows of towering cumulus clouds in a relatively dry environment. The hook-shaped cloud near the horizon (top, center) extends into Canada beyond Edmonton, Alberta. The clouds near the western edge are cirrus with small cumulus beneath. At the southern edge of the hook-shaped cloud and to the right of the dark spot, low stratus and stratocumulus and drizzle prevail, perhaps with some upper cloud cover. Farther to the right, cirrus and altocumulus clouds are thinner and there are no low clouds. The somewhat square, bright patch farther to the right is apparently a view of the northern portion of Lake Winnipeg with a covering of snow and ice, since only broken upper clouds are reported in that area.

Frame E, taken one minute after frame D, reveals much detail to the east and northeast of the large overcast region. The slightly brighter parallel cloud bands which appear as arcs to the upper right of the picture center (indicated by thin arrows) are of particular interest. In this area over northern Minnesota, radar echoes (fig. 1) form a remarkably similar pattern of concentric arcs. (An independent diagnosis of this banded structure from the photos alone would likely be rather difficult because of the lack of contrast in the images.) The bright cloud mass to the lower left extends over eastern Iowa. This is the northern portion of the thundershower structure discussed under frame B. The partly cloudy darker region from the lower left corner of the frame is the extension of the cloudless wedge also shown in that frame. Here, however, much greater detail is available in what appeared in frame B to be a single cloud band pointing southward into the clear area. One hundred minutes later, in frame E, at least two streets of bright shower cloud masses are apparent in this region, along with other isolated groups of cells.

Frame F, taken one minute after frame E, contains a gray region to the left of center which is also visible slightly to the right of the center of frame E. Frame H presents a narrow-angle camera view of a portion of the region indicated on frame F and located near La Crosse, Wis. In this narrow-angle photo a few large cumulus clouds appear in the upper left, with multi-layer frontal precipitation cloudiness commencing in the lower left. Stratocumulus in various banded arrays appears toward the top and right of the central partly cloudy area. Frame F also presents a clear area in the lower right corner which is located along the Ohio Valley. The bright band extending to the right is a mass of low stratus extending eastward along the lower Great Lakes. A cirrus veil covers the stratus and extends northward. No middle cloud exists in this area as indicated by the radiosonde reports.

3. CLOUD FEATURES AND THE SYNOPTIC WEATHER SITUATION

The above discussion permits one to locate geographically the various cloud features seen in the photos. The two

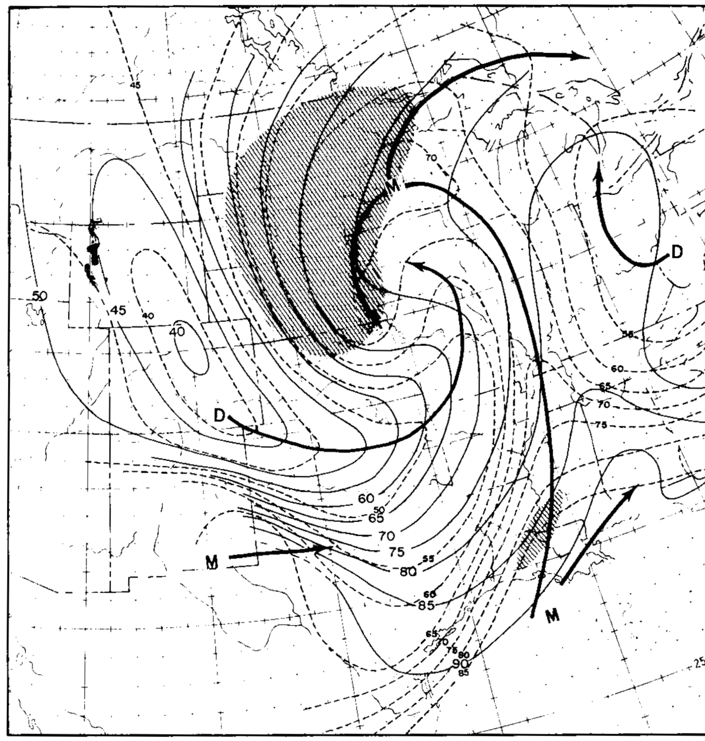

FIGURE 7. Isentropic chart for 300° K.; pressure in solid lines and condensation pressure in dashed lines, 0000 GMT, April 2, 1960. Shading indicates approximate area of saturation.

composite cloud representations in figures 5 and 6 will next be related to the storm structure. Reference will be made to the 2100 GMT sea level chart in figure 1 as well as to the isentropic chart in figure 7 and the north-south and east-west cross sections in figures 8 and 9, all based upon information at 0000 GMT, April 2.

Region I of figure 5 is the post-cold-frontal section of the storm. Considering the fact that the pictures were taken near mid-afternoon local time, it may seem remarkable that this region is so free of even convective-type clouds. The air was extremely dry, however, as indicated by surface reports such as that for Fort Worth which had a temperature of 72° F. and dew point of 28° F. Immediately to the rear of the front along the Texas coast there is a broad band of clouds, which appears brightest to the northeast and also has some small, distinct clear spots embedded in it. Reports from stations along the Texas coast show that this post-frontal cloud band consisted of towering cumulus and stratocumulus types. Reports of any major shower activity in this area, either from surface reports, radar, or sferics, were lacking, however. These clouds were very likely entirely within the warm air above the cold front. Figures 8 and 9 show that the cold air was rather shallow for some distance behind the front so that warm-air cloudiness could have had bases as low as about 5,000 ft. The deeper cold, dry air was not reached until farther west of the front. The faint patches of stratocumulus in frame B may mark the leading edge of the deep cold air.

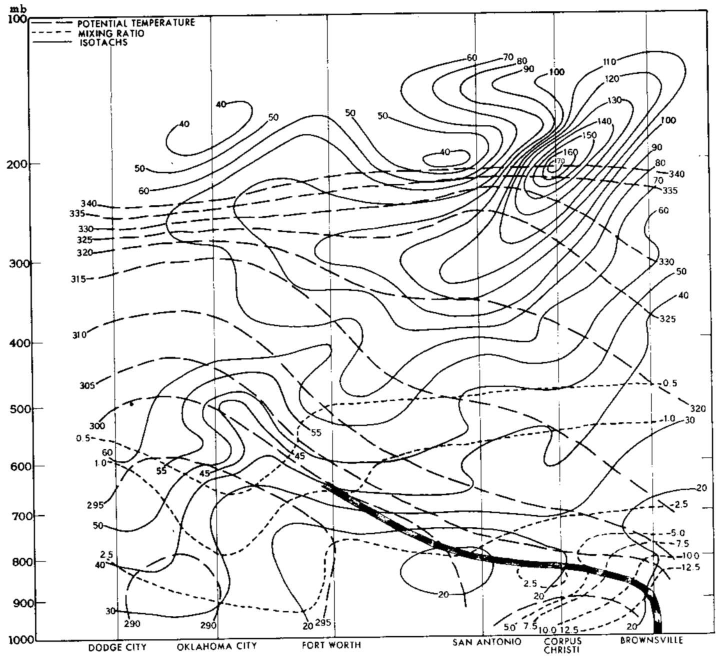

FIGURE 8.—North-south vertical cross-section (isotachs in 10-knot intervals) 0000 GMT, April 2, 1960.

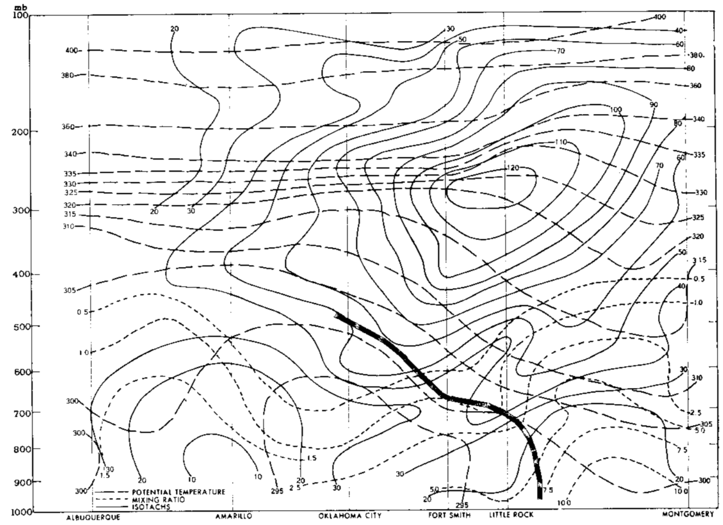

FIGURE 9.—East-west vertical cross-section (isotachs in 10-knot intervals) 0000 GMT, April 2, 1960.

Region II is very moist as indicated by the high condensation pressures on the isentropic surface displayed in figure 7. Clusters of radar echoes shown in figure 1 marked the frontal thunderstorms from Lake Charles, La. northward toward Little Rock, Ark. Heavy clusters of radar echoes and sferics reports blanketed another large thunderstorm area which extended from New Orleans eastward in the warm-frontal zone along the Gulf coast. Upper-level charts indicated a branch of the jet stream extending from near the Mississippi Delta toward central Florida. One might thus speculate that the marked contrast in cloudiness and precipitation, indicated in frame C by the bright coastal cloud band and the reduced activity offshore (see also bottom and lower left in frame B), may reflect differences in the large-scale vertical motion pattern on either side of the jet axis. Aircraft reports indicated a cirrus overcast between 300 and 400 mb. which extended over the thundershower area, but also ended at the Gulf coast.

Region III includes the warm tongue shower activity which extended in a band northward along the Mississippi River to southeastern Iowa. Although surface reports did not generally indicate high humidity in this band, there was evidence of a well developed moist tongue on the isentropic chart (fig. 7). A line of sferics fixes extended through this band from Jackson, Miss. to St. Louis, Mo. Clusters of radar echoes marked the bright "finger" of cloud in frame B near the southern end of this band and similar echoes marked the equally bright cloud clusters in frames E and F to the north.

Region IV is an extension of the post-frontal and frontal region. Close inspection of frame B suggests a veil of thin upper clouds covering the easternmost dark wedge. Radar and surface reports located thundershowers in the northern portion of the brighter central cloud area and southwesterly upper winds could have carried convectively produced upper clouds into the dark wedge. Surface reports required that the occluded front be placed near Des Moines, Iowa at 2100 GMT in the central cloud area. Thus the eastern dark wedge of reduced cloudiness is in the warmer air to the east of the cold front. This is in agreement with reports from stations such as St. Louis which reported partly cloudy skies in the southerly warm flow. If we may digress slightly into region IX (fig. 6), we see similar indications of the frontal position there. Surface data at 1800 GMT suggest that the left-most bright appendage in the dark area in the lower left of frame E is associated with the cold front over southwestern Iowa. Stations with partly cloudy skies were located well to the east of the front, but west of the bright shower band in the moist tongue.

Region V is the southern portion of the area of upslope precipitation. The pattern of ascending, saturated air is indicated on the isentropic surface (fig. 7) by the southwestward curving branch of the moist tongue. Rain and snow had ended in the southeastern portion of this cloud mass and pressures were rising. However, by the time of these photos, new snowfall from the storm had enlarged the area of snow cover to include northeastern Nebraska and the eastern Dakotas. The apparent brightness and lack of texture may thus result, in part, from the presence of the snow field. The question of image contamination by snow fields does not arise insofar as the southern and western cloud boundary is concerned, since snow cover limits are well within the cloudy area. The rather well defined edge of these clouds suggests the desiccating power of the descending motion pattern around its perimeter.

The thin cloud veil in region VI appears to have been generated by shower activity farther to the northwest. The sounding at Lander, Wyo. indicated extremely unstable showery air up to approximately 16,000 ft. The northwesterly flow at such heights was apparently propagating high clouds from this showery source region southeastward across Oklahoma. Denver and Dodge City soundings indicated a cloud base near 620 mb. The thin texture of this cloud veil, as contrasted with the brighter streaks of cloud over Wyoming as seen in frame D, suggests that these clouds may be poor indicators of upward vertical motion. They appear to be barely tolerated by the broad-scale vertical motion pattern. The north-south cross section in figure 8 suggests an explanation for the abrupt cloud streak which appears to terminate the thin cloud veil. (The cross section, fig. 8, is essentially normal to the mid-tropospheric flow as seen on the 500-mb. chart, fig. 11.) Kuettner [4] has discussed observations of similar cloud streaks or bands in association with jet streams. Although the jet stream in this case was far removed from the cloud streak, there is evidence of considerable variation in horizontal wind shear oriented in the same direction as the cloud streak. Close examination of frame B on the original film strip reveals not only the bright cloud line but a faint resumption of cloud farther to the southeast. There is thus an impression that vertical motions in response to the streaks in the horizontal shear created an undular pattern in the cirrus veil—augmenting the cloud in regions of ascending motion and subduing it where sinking motion occurred. The bright streak is located about midway between Oklahoma City and Fort Worth, near the zone of maximum cyclonic shear on the cross section.

In region VII the isentropic chart (fig. 7) suggests that a broad-scale ascending motion area existed in the middle troposphere with air being lifted along the flank of the cold dome. In figure 9 between Albuquerque and Amarillo, air with slightly higher moisture content is noticeable. Soundings in this sector had extreme instability in the lower layers. Dry adiabatic lapse rates extended upward beyond 700 mb. at Albuquerque, N. Mex., and Amarillo and Midland, Tex. The unstable air terminated at the tropopause near 400 mb. The cellular structure in frame A thus appears to be made up of a cirrus veil above large cumulus groups.

Region VIII contains a variety of cloud types. Unfortunately, the foreshortened view precludes any serious attempt to distinguish one type from another. The "hook-shaped" western boundary of the cloud is located in an air mass of Pacific origin where the previously mentioned cirrus and small cumulus clouds were reported. The sharpness of this western edge may reflect an orographic downslope motion to the east of the Canadian Rockies since westerly winds aloft were reported in the Edmonton–Calgary area. Farther east the quasi-stationary front shown in figure 1 bounded a colder and much drier polar continental air mass. The stratiform clouds along the west limb of the front were probably covered by middle and upper clouds which extended eastward into the partly cloudy area over the colder air mass. No low clouds were reported in the dry polar air—the dull gray patches being thinner areas of middle and high clouds.

Region IX has been discussed in connection with the overlapping regions to the south. The central portion of the widespread continuous rain and snow area is located in eastern South Dakota. The cloud and radar echo areas, mentioned in connection with frame E, appear to be near the perimeter of the frontal upslope activity in the isentropic pattern of figure 7, and on the very fringe of the region of frontal precipitation as indicated by surface reports. In this area and to the north, cloud brightness in the photos may be affected partly by an older snow cover extending into north central North Dakota and eastward across northern Minnesota and northern Wisconsin. Another isolated line of radar echoes is indicated in figure 1 near Rapid City, S. Dak.

In contrast to the northern Minnesota cloud arcs which existed in a region having a marked frontal inversion, the Rapid City sounding revealed extreme instability in the lower layers. The north-south alignment of the echoes with the flow at lower levels over the western Dakotas suggests a band of convective activity induced from the ground rather than from frontal lifting. It is quite remarkable that all cloud activity ceases rather abruptly at the western edge of the large frontal cloud mass. A combination of factors seems to be involved since the edge appears to coincide at all cloud levels. Reversal of the mid-tropospheric vertical motion from ascending to descending at the cloud edge may have been the predominant factor. The filmy appearance of the edges of cloud bands in frame G, coupled with the suggestion of downslope motion over the Canadian and Montana Rockies, suggests that lateral mixing of dry air may also have assisted the process of middle and upper cloud decay along this western edge. At lower levels, moist northeasterly trajectories within the upslope cloud mass, in contrast with drier northwesterly trajectories farther west, may have favored such an abrupt edge within the convective layers.

Region X presents the situation in the eastern portion of the storm's perimeter. The isentropic chart in figure 7 indicates an eastward-branching moist tongue with a lateral admixture of drier air from Kentucky and Tennessee. No middle clouds were indicated by the soundings, nor by the isentropic chart which intersected above a strong low-level inversion in this area. Presumably a pattern of overrunning motion farther aloft produced clouds, since aircraft reported cirrus in conformity with the filmy white clouds seen throughout the central and eastern Lakes region in frame F. Soundings at Dayton, Ohio, Flint, Mich., and Pittsburgh, Pa. indicated a strong temperature inversion and moisture lapse at 3000–5000 ft. Reports of fog accompanying the low clouds in this strong inversion area suggest a rather solid layer of fog, stratus, and stratocumulus from the ground up.

Such density of low cloud may help to explain the very bright, solid appearance of the band as seen from above.

The foregoing discussion suggests several problems which will arise in using cloud photos as an analytic tool. For example, the bright cloud band in frame F might be considered to be a cloud system similar to that in the lower right portion of frame C. Careful photographic work and interspersed narrow-angle shots to indicate detail would probably suffice to isolate the cellular showery cloud system from the stratiform system. Certainly, brightness alone does not appear to be a dependable indicator of cloud type.

Thin cirrus cloud veils may also present some uncertainties since slight ascending motion in the broad-scale sense might allow clouds such as those in frame A to be transported far from their source region which contains the marked ascending motion which one may wish to identify.

Although foreshortened views are desirable in expressing a broad cloud pattern, aspect presents a problem. Looking again at frame B as an example of the cloud structure of a cyclone, it should be pointed out that foreshortened positions even with cellular texture tend to assume a solid stratiform appearance and caution must be used in these areas. Sun glint and land-water undersurface contrasts are other factors which tend to confuse relative brightness of clouds.

Despite such problems the preceding discussion has indicated the correspondence between distinctive features of the cloud photos and a synoptic weather situation analyzed with standard observational material.

4. CLOUD PHOTOS AND OBJECTIVE MAP ANALYSIS

One of the main points in support of cloud observations from meteorological satellites has been their potential use in providing observations over sparse data regions of the earth, especially in oceanic areas. Apart from direct operational application as a warning of the existence of various severe large-scale weather phenomena, such data would also be expected to contribute to our ability to predict the motion and evolution of storms generally. This contribution might best be included in an objective fashion in the process of numerical weather prediction. Since modern numerical weather prediction is basically an initial value problem, such added forecast skill could be considered to be a reflection of the degree to which the new information from meteorological satellites can be used to delineate better the three-dimensional state of the atmosphere at a particular time selected as the starting point for a numerical prediction.

The brief discussion which follows is without results but is presented to indicate current efforts in this direction.

If one now admits cloud photographs such as those obtained from TIROS as the new information in sparse data regions, a new question arises: how does one correct

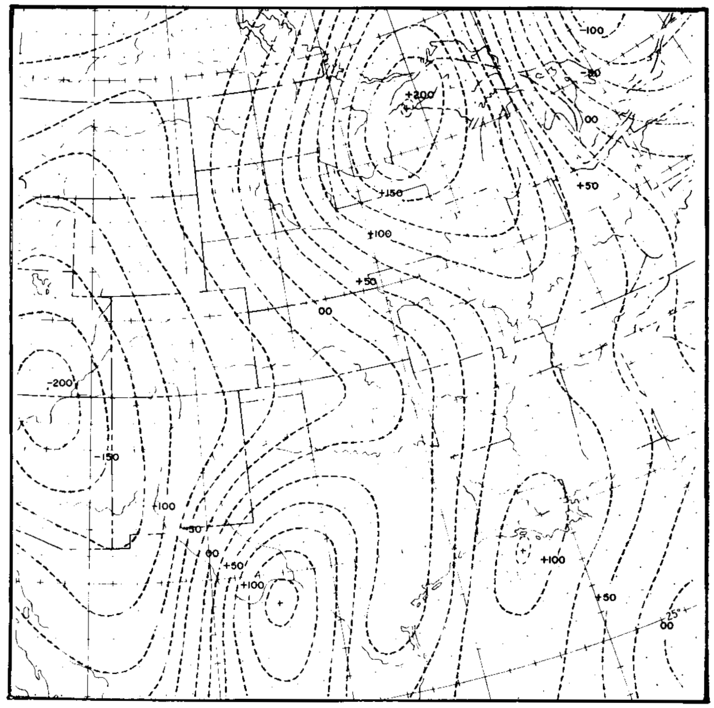

FIGURE 10.—600-mb. vertical motion chart (arbitrary units with plus areas indicating ascending motion), 0000 GMT, April 2, 1960.

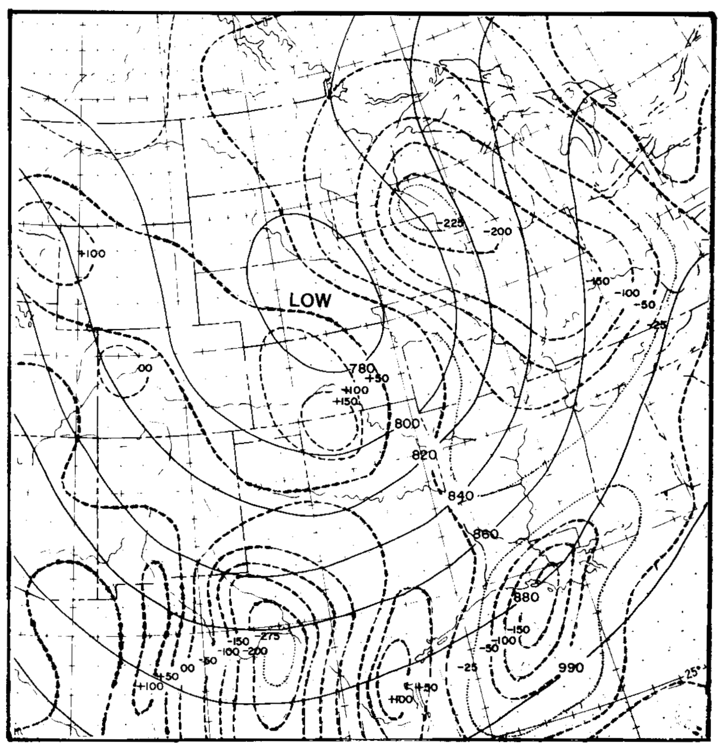

FIGURE 11.—500-mb. contours (solid lines) with vorticity advection (dashed lines, and in arbitrary units), 0000 GMT, April 2, 1960.

or refine first estimates of the wind field and the field of geopotential obtained from wind and pressure data—the common input information for numerical weather prediction—through the addition of cloud photo observations? The suggestion involves using the cloud photos as indications of broad-scale vertical motion patterns. Figure 10 is an expression of the broad-scale vertical motion at 600 mb. over the Midwest about 5 hours after TIROS cloud photos of figures 2, 3, and 4. (The units are arbitrary with plus areas signifying ascending motion.) In general there is good agreement between the vertical motion chart and the cloud analysis—the principal region of ascending motion corresponding to the frontal activity and moist tongue, with a secondary maximum of ascending motion near the Louisiana coast. The vertical motion patterns in turn are, of course, related to the horizontal fields of wind and geopotential through the divergence patterns specified by these fields. From a simple atmospheric model the divergence at 500 mb. may be approximated by the advection of vorticity at that level. Figure 11 presents the 500-mb. chart with vorticity advection. With change of sign this pattern strongly resembles the vertical motion chart in figure 10. The suggestion thus involves the adjustment of a preliminary analysis of the height of a mid-tropospheric pressure surface in regions of sparse data so that the pattern of vorticity advection is compatible with the mid-tropospheric broad-scale cloud pattern as revealed by satellite cloud photos. Despite the empiricism involved in deriving divergence from cloud patterns, preliminary comparisons of original 500-mb. analyses over regions of good data with degraded 500-mb. analyses, together with corresponding cloud patterns, are encouraging. Following the work of Cressman [5] and Sasaki [6], efforts toward production of such a corrective analysis procedure by high speed computers are now under way.

5. CONCLUSION

In the present descriptive study, standard meteorological measurements over a dense data network have been compared to TIROS cloud photographs for a particular synoptic situation. The utility of such a wealth of photo information over a broad land expanse has been suggested by these comparisons. It appears likely that a series of such studies can generate semi-empirical relationships which would be of great assistance in making adjustments and corrections to the analysis of upper-air charts over sparse data areas. In a more quantitative vein, a method has been suggested whereby such cloud data could be utilized in a computer-produced, objective map analysis.

ACKNOWLEDGMENTS

Special acknowledgment is given to the Geophysical Research Directorate and Stanford Research Institute for their radar information concerning this storm, and also to Detachment 4, 4th Weather Group and the Severe Local Storm Center of the Weather Bureau at Kansas City, Mo. for their radar and sferics data. Acknowledgment is extended to Detachment 19, 9th Weather Squadron of March Air Force Base and Detachment 11, 26th Weather Squadron, Barksdale Air Force Base for their nephanalysis and other valuable charts which aided in the writing of this report.

REFERENCES

1. S. Steinberg, W. G. Stroud, et al., "Roundup on TIROS I" (a series of articles relating to engineering aspects of TIROS I), *Astronautics*, No. 5, 1960, pp. 32–45.
2. S. Fritz and H. Wexler, "Cloud Pictures from Satellite TIROS I," *Monthly Weather Review*, vol. 88, No. 3, Mar. 1960, pp. 79–87.
3. R. C. Doolittle, L. Miller, and I. Ruff, "Geographic Location of Cloud Features," Appendix I of "Some Meteorological Results from TIROS I," by Staff, Meteorological Satellite Laboratory, U.S. Weather Bureau, in a report by National Aeronautics and Space Administration. (In press.)
4. J. Kuettner, "The Band Structure of the Atmosphere," *Tellus*, vol. 11, No. 3, Aug. 1959, pp. 267–294.
5. G. P. Cressman, "An Operational Objective Analysis System," *Monthly Weather Review*, vol. 87, No. 10, Oct. 1959, pp. 367–374.
6. Y. Sasaki, "An Objective Analysis Based on the Variational Method," *Journal of the Meteorological Society of Japan*, Series II, vol. 36, No. 3, June 1958, pp. 77–88.